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Recovery of Byproduct Heavy Minerals From Sand and Gravel Operations in Central and Southern California

By J. M. Gomes, G. M. Martinez, and M. M. Wong

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
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RECOVERY OF BYPRODUCT HEAVY MINERALS FROM SAND AND GRAVEL OPERATIONS IN CENTRAL AND SOUTHERN CALIFORNIA

by

J. M. Gomes,[1] G. M. Martinez,[2] and M. M. Wong[3]

ABSTRACT

The Bureau of Mines has investigated the occurrence and recovery of byproduct heavy minerals from sand and gravel operations as a means of assessing the Nation's resources. Sand samples from 63 locations in central and southern California were treated to yield heavy-mineral concentrates. The mineral compositions of the concentrates were characterized by chemical and mineralogical examinations. Additional large quantities of concentrates were prepared from selected deposits that contained significant quantities. Beneficiation studies were performed on these concentrates to recover individual mineral products. Gold was recovered by amalgamation; platinum-group metals and radioactive minerals by flotation; magnetite, ilmenite, and chromite by magnetic and high-tension separation techniques.

INTRODUCTION

The Bureau of Mines has assessed central and southern California sand and gravel deposits to determine their heavy mineral (HM) contents. Recovery of HM byproducts from sand and gravel operations would promote conservation and subsequently maximize utilization of the Nation's resources.

The recovery of gold from sand and gravel operations has been practiced by some operators for decades, but the recovery of other heavy minerals to date has been neglected. The recovery of heavy minerals from these sources would not incur additional environmental impact, as these materials are byproducts.

This is our second report on the recovery of byproduct heavy minerals from California sand and gravel operations. An earlier report described the

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recovery of byproduct heavy minerals from operations in northern California (7).[4] The area covered in this report, central and southern California, is significant because of the large tonnage of sand and gravel produced, approximately 80 million tons annually, and its proximity to mineralized areas. The major alluvial deposits that furnish the sand and gravel are derived from mineralized areas in the Sierra Nevada, Coast, Traverse, and Peninsular Ranges (6).

The northern San Joaquin Valley is adjacent to the famous Mother Lode gold belt, and gold is recovered from several sand and gravel operations in this area. Sand and gravel operations in Los Angeles and San Diego Counties are adjacent to lesser gold-producing districts such as Acton, San Gabriel Mountains, and Julian-Banner. Gold was recovered from the San Gabriel River in 1835 by Mexican miners (2), 13 years before Marshall's famous gold discovery at Coloma in northern California. None of the operations in southern California presently recover gold or any other heavy minerals.

HM concentrates (black sands) from California alluvial deposits generally contain magnetite, ilmenite, hematite, chromite, zircon, garnet, and sometimes gold, platinum-group metals (PGM), scheelite, and cinnabar (5). Several of these minerals have economic potentials, and their values continue to increase. Some of these minerals, e.g., zircon, chromite, and PGM, are obtained in this country mainly by imports.

Only a few successful attempts have been reported in the literature on recovering heavy minerals other than gold as byproducts from sand and gravel operations. Iron ore was recovered in England (1). The Bureau of Mines has investigated the recovery of ilmenite, zircon, kyanite, and rutile in the Southeastern United States (3-4). Free gold has been recovered from sand and gravel operations in California for more than 40 years. In recent years, about one-half of California's gold production has been from sand and gravel operations. Presently, the largest gold producer in California is a sand and gravel operation in Sacramento County.

The objectives of this investigation were (1) to determine HM contents of sand and gravel deposits; (2) to investigate the recovery of HM concentrate from deposits that showed significant HM contents; and (3) to prepare marketable mineral products from selected concentrates.

HEAVY-MINERAL SAMPLING AND CHARACTERIZATION

The locations of central and southern California operations that provided samples for this investigation are shown in figures 1 and 2. To simplify the tabulation of results, central California was divided into four areas: (I) San Francisco Bay, (II) Central Coast, (III) Northern San Joaquin Valley, and (IV) Southern San Joaquin Valley. Southern California was divided into three areas: (V) Mojave Desert-Imperial Valley, (VI) Los Angeles area, and (VII) San Diego area. The sand and gravel operations are principally located in

[4]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

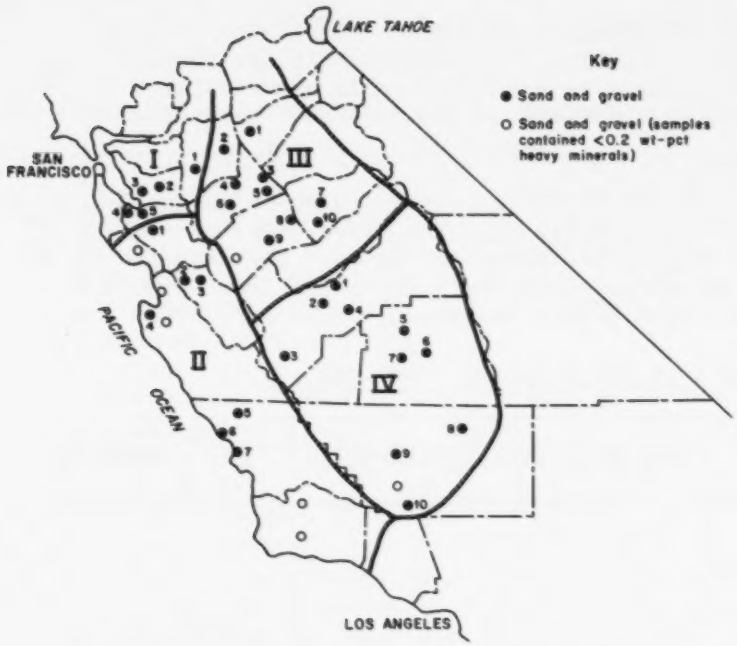

FIGURE 1. - Central California sample locations.

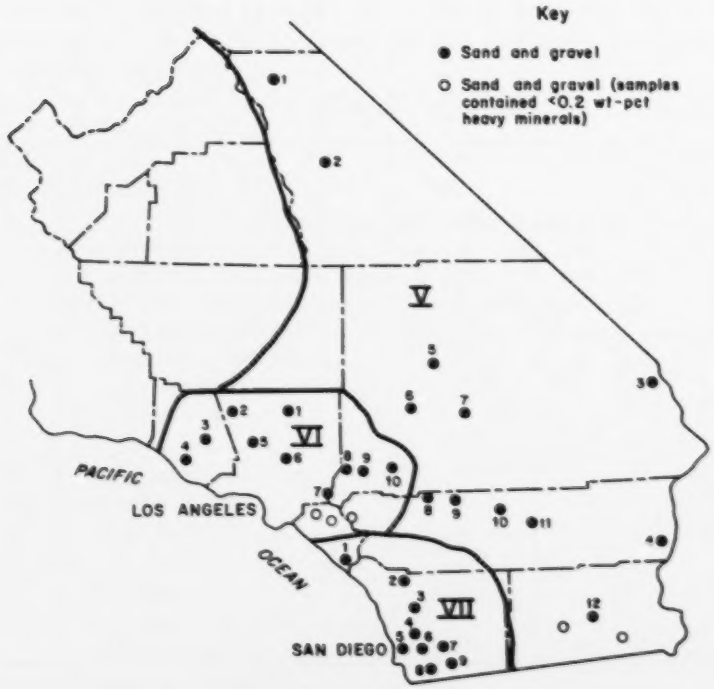

FIGURE 2. - Southern California sample locations.

Quarternary alluvial deposits in stream channels and flood plains. These deposits are mainly derived from the weathering of mineralized areas in the major mountain ranges.

The sampling procedure began by obtaining 40- to 50-lb grab samples of washed cement or mortar sand from the various sand and gravel operations. These were grab samples taken from the stockpiles; no attempts were made to obtain representative samples of the total deposits, which would involve extensive sampling and considerable work at each operation. HM concentrates were prepared from sand samples using a spiral concentrator. The concentrates were given a mineralogical examination and analyzed for Cr_2O_3, Fe_2O_3, TiO_2, ZrO_2, gold, silver, platinum-group (PGM), and any other metals of economic significance. The approximate concentrations of chromite, ilmenite, and zircon in the deposit were then calculated. The magnetite concentration was determined by low-intensity (LI) magnetic separation and chemical analysis. An electron microprobe analysis was made on some samples to determine the mineral association and trace elements. The total HM content was determined by heavy-medium separation using diiodomethane ($C_2H_2I_2$) with a sp gr of 3.3.

Samples showing less than 0.2 wt-pct HM in the deposits were not reported in the tables

but their locations (unnumbered) are shown in figures 1 and 2. The results reported in the tables are based on the sand fraction, usually the minus 1/4-inch material in the deposits. Because of the variable sand contents in most individual deposits, results were not calculated for the total inplace deposits.

Results of samples from the San Francisco Bay area are shown in table 1. The samples contained 0.3 to 1.0 wt-pct total HM. The major heavy minerals present were magnetite, up to 7 lb/ton, and ilmenite, up to 3 lb/ton. Two of the samples contained 1 lb/ton chromite. Gold contents varied from <0.0001 to 0.0006 oz/ton, and an Alameda Creek sample contained 0.0006 oz/ton Pt.

TABLE 1. - Samples from San Francisco Bay area (I)

Map No.[1]	Source and location	Total HM, wt-pct	Lb/ton			Oz/ton	
			Magnetite	Ilmenite	Chromite	Gold	Platinum
1	Corral Hollow Creek:						
	Tracy (Lone Star).	0.9	2	2	<1	0.0001	<0.0001
	Tracy (Teichert)..	.4	3	3	<1	.0003	<.0001
2	Arroyo Del Valle:						
	Pleasanton.....	.3	3	1	<1	.0004	<.0001
3	Alameda Creek:						
	Sunol (Lone Star).	.3	1	1	<1	.0001	<.0001
	Niles (Jamieson)..	.4	6	<1	<1	.0006	.0006
	Fremont-Griffiths.	.3	7	<1	<1	.0004	.0002
4	Guadalupe Creek:						
	Los Gatos.....	.7	2	<1	1	<.0001	<.0001
5	Coyote Creek:						
	Coyote.....	1.0	6	<1	1	<.0001	<.0001

[1]Locations in figure 1.

Results of samples in the Central Coast area are shown in table 2. The samples contained 0.2 to 0.8 wt-pct total HM. Magnetite, up to 5 lb/ton, was the major mineral present. The Morro Bay and San Simeon samples contained 3 and 4 lb/ton chromite, respectively, and the Carmel River sample contained 4 lb/ton garnet. Gold and platinum contents in this area were minimal or nonexistent.

TABLE 2. - Samples from Central Coast area (II)

Map No.[1]	Source and location	Total HM, wt-pct	Lb/ton				Gold, oz/ton
			Magnetite	Ilmenite	Chromite	Garnet	
1	Uras Creek: Gilroy	0.3	4	<1	<1	<1	<0.0001
	San Benito River:						
2	San Juan Bautista	.8	5	2	<1	<1	<.0001
3	Hollister.....	.4	4	<1	<1	<1	<.0001
4	Carmel River:						
	Carmel.....	.3	<1	<1	<1	4	<.0001
5	Salinas River:						
	Templeton.....	.2	2	<1	<1	<1	<.0001
6	San Simeon Creek:						
	San Simeon.....	.7	2	<1	4	<1	<.0001
7	Beach sand:						
	Morro Bay.....	.3	<1	2	3	<1	<.0001

[1]Locations in figure 1.

Results from samples in the Northern San Joaquin Valley are shown in table 3. The total HM contents ranged from 0.6 to 3.0 wt-pct. The major heavy minerals in the area were magnetite, 1 to 20 lb/ton, and ilmenite, 2 to 23 lb/ton. The gold contents varied from <0.0001 to 0.003 oz/ton, and the platinum contents were 0.0001 oz/ton or less. Most of the plants in this area presently recover gold. The samples were taken from material that had passed through the gold savers, so the gold values shown are considerably lower than those in the original material.

TABLE 3. - Samples from northern San Joaquin Valley (III)

Map No.[1]	Source and location	Total HM, wt-pct	Lb/ton		Oz/ton	
			Magnetite	Ilmenite	Gold	Platinum
	Calaveras River:					
1	Jenny Lind.....	3.0	8	23	0.0030	0.0001
2	Bellota.....	1.4	1	2	<.0001	.0001
	Stanislaus River:					
3	Knights Ferry.....	2.2	20	8	.0004	<.0001
4	Riverbank.....	2.8	6	13	<.0001	<.0001
	Toulumne River:					
5	Waterford.....	.6	5	5	<.0001	.0001
6	Modesto.....	1.8	6	6	<.0001	.0001
	Merced River:					
7	El Portal.....	.9	2	2	.0001	<.0001
8	Snelling.....	2.2	5	5	<.0001	.0001
9	Cressy.....	1.0	3	3	.0003	<.0001
10	Mariposa Creek:					
	Mormon Bar.....	1.0	5	5	<.0001	<.0001

[1]Locations in figure 1.

The results of samples from the southern San Joaquin Valley are shown in table 4. These samples showed total HM contents of 0.3 to 2.9 wt-pct. The major heavy minerals present were magnetite, 1 to 40 lb/ton, and ilmenite, 1 to 5 lb/ton.

TABLE 4. - Samples from southern San Joaquin Valley (IV)

Map No.[1]	Source and location	Total HM, wt-pct	Lb/ton			Oz/ton	
			Magnetite	Ilmenite	Chromite	Gold	Platinum
	San Joaquin River:						
1	Friant.....	1.6	21	5	<1	0.004	0.004
2	Pinedale.....	.6	2	2	<1	<.0001	<.0001
3	Los Gatos Creek:						
	Coalinga.....	2.6	23	3	3	<.0001	<.0001
4	Kings River:						
	Centerville.....	1.0	12	4	<1	<.0001	<.0001
5	Kaweah River:						
	Lemon Cove.....	2.9	40	1	<1	<.0001	<.0001
	Tule River:						
6	Success.....	.7	6	3	<1	<.0001	<.0001
7	Porterville.....	.3	5	4	<1	.0005	<.0001
8	Canebrake Wash:						
	Onyx.....	2.3	24	5	<1	<.0001	<.0001
9	Kern River:						
	Oildale.....	.6	3	2	<1	.0003	<.0001
10	Cuddy Creek:						
	Frazier Park.....	.3	1	2	<1	.0001	<.0001

[1]Locations in figure 1.

The Los Gatos Creek samples contained 3 lb/ton chromite. The gold contents varied from <0.0001 to 0.004 oz/ton. Presently the two plants on the San Joaquin River and the one on the Kaweah River recover gold. Platinum content of the San Joaquin River sample taken at Friant was 0.004 oz/ton. Platinum was not detected in the other San Joaquin River sample taken at Pinedale.

The results of samples from the Mojave Desert and Imperial Valley are shown in table 5. The total HM contents of the samples varied from 0.5 to 2.1 wt-pct. The major heavy mineral present was magnetite, 2 to 35 lb/ton; ilmenite was present in quantities ranging from 2 to 6 lb/ton. Gold and platinum contents were below detection limits in all samples from this area.

TABLE 5. - Samples from Mojave Desert-Imperial Valley (V)

Map No.[1]	Source and location	Total HM, wt-pct	Lb/ton	
			Magnetite	Ilmenite
	Owens River:			
1	Bishop.....	2.1	35	2
2	Lone Pine.....	2.0	21	2
	Colorado River:			
3	Needles.....	.7	7	6
4	Blythe.....	1.2	9	2
	Mojave River:			
5	Barstow.....	.7	4	4
6	Victorville.....	.6	7	2
7	Crystal Creek:			
	Lucerne Valley.....	1.3	9	5
	San Gorgonio River:			
8	Beaumont.....	1.3	9	5
9	Cabezon.....	1.1	15	4
	Whitewater River:			
10	Whitewater.....	1.7	11	4
11	Indio.....	1.3	11	2
12	East Highline: El Centro..	.5	2	2

[1]Locations in figure 2.

The results of samples from the Los Angeles area are shown in table 6. The HM contents varied from 0.4 to 4.0 wt-pct. The major heavy mineral present was magnetite, 1 to 28 lb/ton; the next most prevalent mineral was ilmenite, 1 to 11 lb/ton. Gold contents in this area varied from <0.0001 to 0.0013 oz/ton, and platinum was not detected in any of the samples taken from this area. Presently none of the plants in the Los Angeles are recover gold.

TABLE 6. - Samples from Los Angeles area (VI)

Map No.[1]	Source and location	Total HM, wt-pct	Lb/ton		Gold, oz/ton
			Magnetite	Ilmenite	
1	Little Rock Creek: Palmdale..	2.4	28	4	<0.0001
	Santa Clara River:				
2	Saugus.....	4.0	11	7	<.0001
3	Santa Paula.....	.8	1	2	<.0001
4	Saticoy.....	1.6	6	8	.0013
5	Big Tujunga River: Sun Valley	4.0	28	11	.0001
6	San Gabriel River:				
	El Monte.....	1.1	6	3	.0002
	Irwindale.....	1.3	15	3	.0007
	Azusa.....	.8	4	2	.0005
7	Temescal Creek: Corona.....	1.0	11	6	<.0001
8	Lytle Creek: San Bernardino..	1.0	4	3	<.0001
	Santa Ana River:				
9	Colton.....	.4	4	1	<.0001
10	Redlands.....	1.8	5	3	<.0001

[1]Locations in figure 2.

The results of samples from the San Diego area are shown in table 7. The total HM contents varied from 0.4 to 1.8 wt-pct. Ilmenite and magnetite were the two major heavy minerals present; magnetite contents varied from 1 to 14 lb/ton and ilmenite contents from 1 to 17 lb/ton. Gold contents varied from 0.0002 to 0.0025 oz/ton. All the samples in the area contained some gold. Presently there are no plants in the San Diego area recovering gold.

TABLE 7. - Samples from San Diego area (VII)

Map No.[1]	Source and location	Total HM, wt-pct	Lb/ton			Gold, oz/ton
			Magnetite	Ilmenite	Garnet	
1	San Juan Creek:					
	San Juan Capistrano..	0.4	1	4	3	0.0008
2	San Luis Rey River:					
	Pala.....	1.8	14	4	<1	.0006
3	Santa Ysabel Creek:					
	San Pasqual.....	1.8	4	13	<1	.0005
	San Diego River:					
4	Lakeside.....	.8	2	2	<1	.0007
5	Mission Valley.....	.5	1	1	<1	<.0001
	Sweetwater River:					
6	Jamacha.....	1.4	10	17	<1	.0025
7	Sloan Canyon.....	1.1	6	5	<1	.0010
	Otay River:					
8	Chula Vista.....	1.1	2	9	<1	.0002
9	Birch Pit.....	.7	2	7		.0005

[1]Locations in figure 2.

Beneficiation

Seven samples were selected for beneficiation studies. Primary concentrates were obtained from these samples by treating 300 to 500 lb of cement or mortar sand with a spiral concentrator. HM recoveries varied from 87 to 99 pct. The primary concentrates weighing 20 to 30 lb were then treated again on the spiral to recover cleaner concentrates containing 27 to 88 wt-pct total HM. HM recoveries in the cleaner concentrates varied from 56 to 93 wt-pct. The results of HM recoveries are shown in table 8. The analyses of the cleaner concentrates are shown in table 9.

TABLE 8. - Recovery of HM from large sand samples

Map No.	Source and location	HM content, wt-pct			HM recovery, pct	
		Heads	Primary Concentrate	Cleaner Concentrate	Primary	Cleaner
II-6	San Simeon Creek: San Simeon	0.7	6	27	99	93
III-8	Merced River: Snelling.....	1.2	14	85	98	88
IV-1	San Joaquin River: Friant.....	1.8	21	88	99	90
VI-5	Big Tujunga River: Sun Valley.....	4.0	16	79	95	80
VI-6	San Gabriel River: Irwindale.....	1.3	11	57	87	66
VII-7	Sweetwater River: Sloan Canyon.....	1.1	13	85	98	90
VII-9	Otay River: Birch Pit.....	.7	15	76	89	56

TABLE 9. - Analysis of HM cleaner concentrates

Map No.	Source and location	Wt-pct				Oz/ton	
		Cr_2O_3	Fe_2O_3	TiO_2	ZrO_2	Au	Pt
II-6	San Simeon Creek: San Simeon.....	5.00	16	1.8	0.1	<0.0001	<0.0001
III-8	Merced River: Snelling	2.60	63	3.9	.5	.080	.004
IV-1	San Joaquin River: Friant.....	.05	72	3.7	.4	.07	.02
VI-5	Big Tujunga River: Sun Valley.....	.02	42	21.0	.2	.006	<0.0001
VI-6	San Gabriel River: Irwindale.....	.06	47	6.0	.3	.02	<0.0001
VII-7	Sweetwater River: Sloan Canyon.....	.02	49	10.0	.2	.09	<0.0001
VII-9	Otay River Birch Pit.....	.08	35	25.0	.1	.02	<0.0001

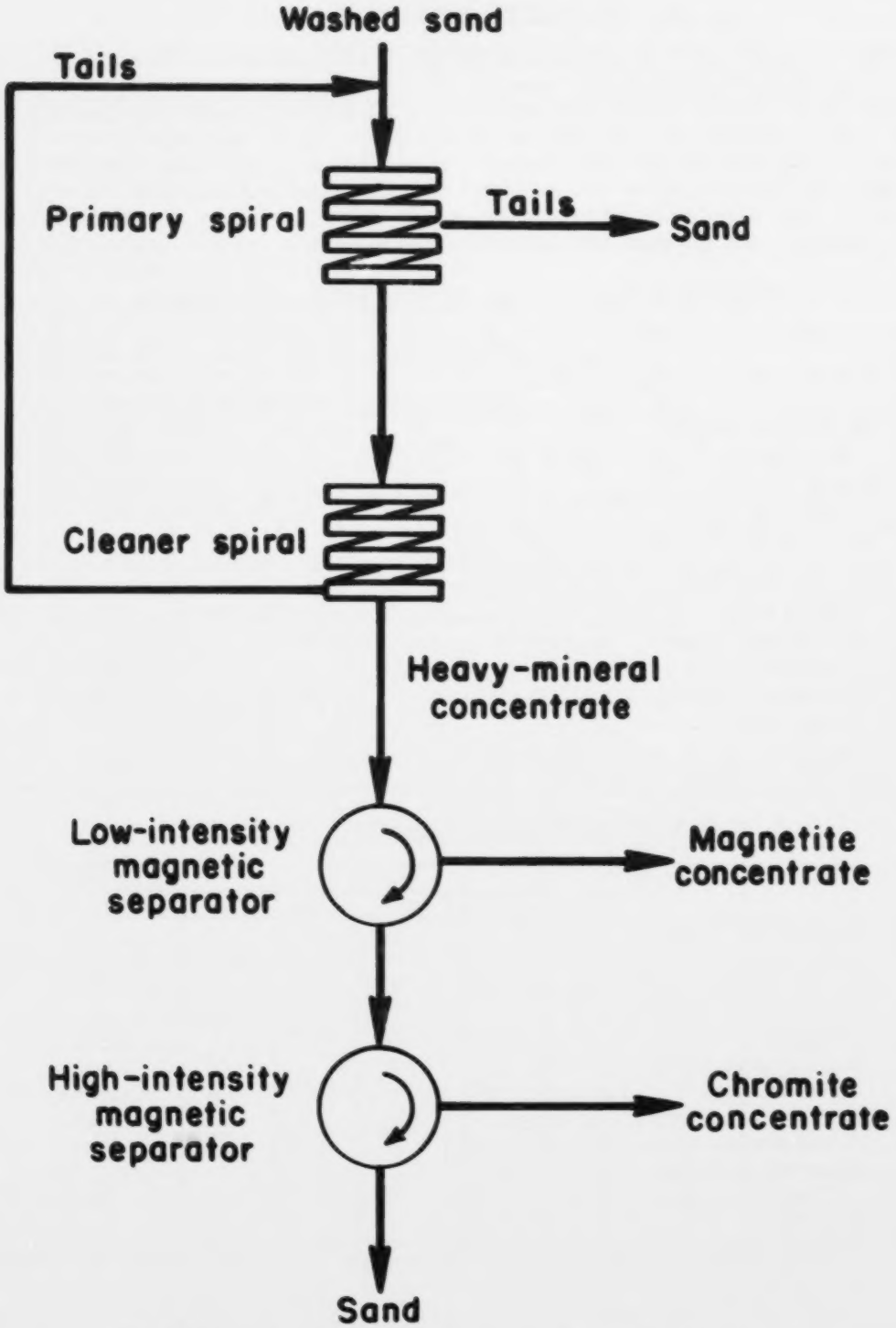

FIGURE 3. - Processing sequence for San Simeon Creek sand.

The San Simeon Creek samples were subsequently selected to be investigated for chromite recovery; Merced River (Snelling) and San Joaquin River samples were investigated for the recoveries of gold, magnetite, platinum, and radioactive minerals. The Big Tujunga River, San Gabriel River, Otay River, and Sweetwater River samples were investigated for the recoveries of gold, magnetite, and ilmenite.

Fractionation of Heavy Mineral Concentrates

San Simeon Creek

A processing sequence for the recovery of chromiferous magnetite and a low-grade chromite concentrate from the San Simeon Creek sample is shown in figure 3. Analysis of the products is shown in table 10. The low-intensity (LI) magnetic fraction contained 78 wt-pct Fe_2O_3 and 8.5 wt-pct Cr_2O_3; this product would be considered a chromiferous magnetite. Of the Cr_2O_3 recovered, 85 pct was in the high-intensity (HI) magnetic fraction containing 22 wt-pct Cr_2O_3, or about 32 wt-pct chromite ($FeCr_2O_4$). The low-grade chromite concentrate contained 29 wt-pct Fe_2O_3 and 1.5 wt-pct TiO_2.

TABLE 10. - Recovery of magnetite and chromite from San Simeon Creek HM concentrates

Product	Wt-pct	Analysis, wt-pct			Distribution, pct
		Fe_2O_3	Cr_2O_3	TiO_2	Cr_2O_3
Cleaner concentrate	100	16.0	5.0	1.8	100
LI magnetic.....	7	78.0	8.5	3.4	10
HI magnetic.....	24	29.0	22.0	1.5	85
HI nonmagnetic.....	69	2.5	.4	1.6	5

Merced River

The processing sequence for recovering gold, magnetite, platinum-group metals (PGM), radioactive minerals, ilmenite, and chromite from Merced River (Snelling) sand sample is shown in figure 4. This sample contained more potential economic minerals than any other sample. The analysis of products

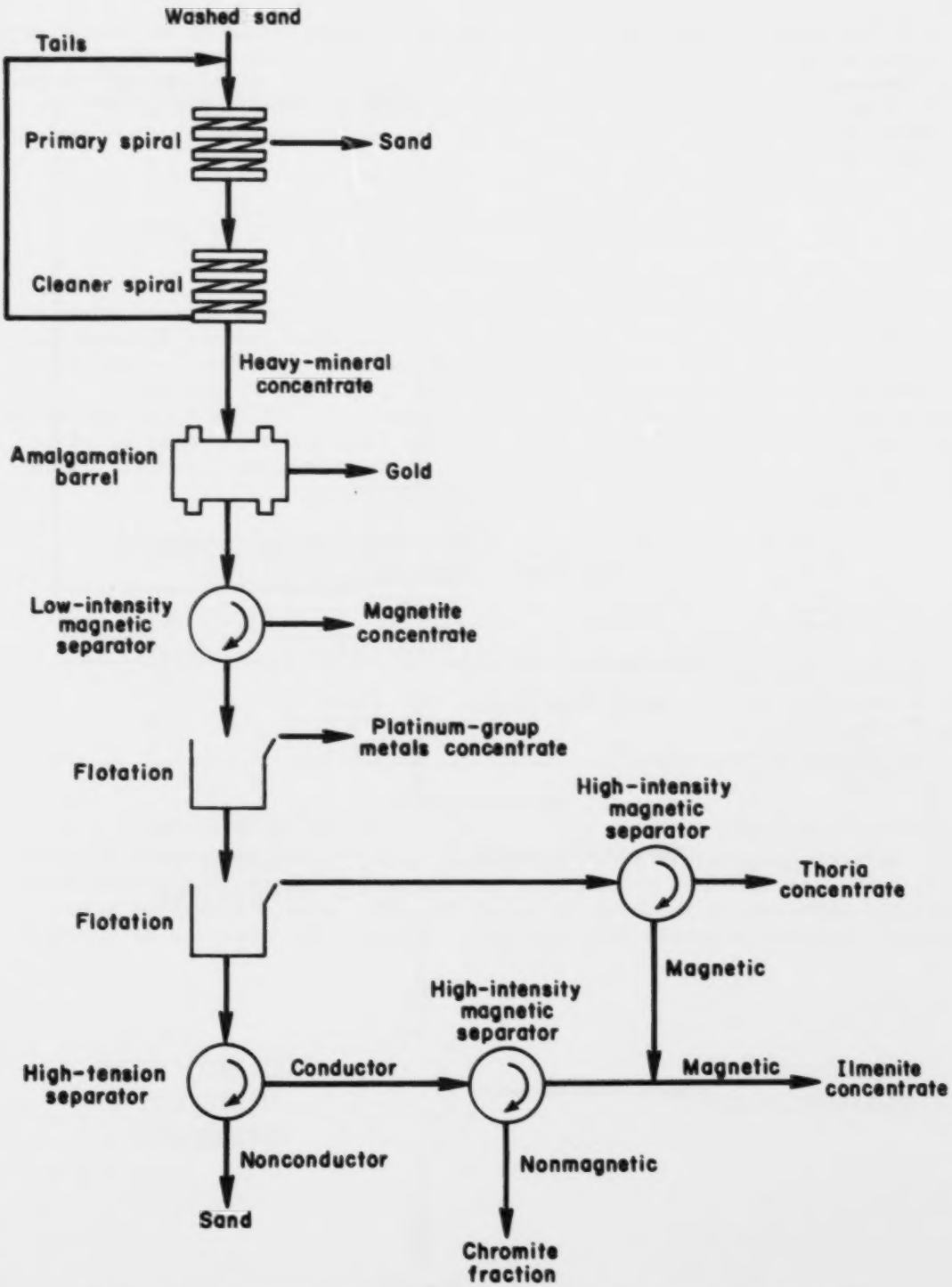

FIGURE 4. - Processing sequence for Merced and San Joaquin Rivers sand.

and distribution of major constituents are shown in tables 11 and 12. The cleaner concentrate, containing 0.08 oz/ton gold, was first treated by amalgamation to recover over 95 pct of the gold. A magnetite product equal to 58 pct of the concentrate was recovered next. The magnetite product contained, in wt-pct: Fe_2O_3, 93; Cr_2O_3, 1.1; and TiO_2, 1.9. The LI nonmagnetic fraction was treated by xanthate flotation for the recovery of a PGM concentrate. About 88 pct of the platinum was recovered in a concentrate containing 2.5 oz/ton Pt. The PGM concentrate also contained 0.30 oz/ton Ir and 0.1 oz/ton Os. Other platinum-group minerals were present only in trace quantities. Electron microprobe examination showed the major platinum mineral to be sperrylite ($PtAs_2$).

TABLE 11. - Analysis of products from Merced River HM concentrates

Product	Wt-pct	Analysis, wt-pct					Pt, oz/ton
		Fe_2O_3	Cr_2O_3	Ti_2O_3	ThO_2	U_3O_8	
Head[1] (cleaner concentrate).....	100	62.8	2.6	3.9	0.72	0.11	0.004
LI magnetic separation:							
Magnetic.....	58	93.0	1.1	1.9	<.05	<.02	.001
Nonmagnetic.....	42	21.1	4.6	6.7	1.70	.27	.009
Platinum flotation (LI nonmagnetic):							
Concentrate (PGM).....	.14	ND	ND	ND	ND	ND	2.500
Tails.....	41.9	21.1	4.6	6.7	1.70	.27	.001
Thorium-uranium flotation (platinum flotation tails):							
Concentrate.....	5	31.8	4.2	16.6	8.20	1.44	ND
Tails.....	37	19.7	4.6	5.4	.83	.11	ND
HI magnetic separation (thorium-uranium flotation concentrate):							
Nonmagnetic (thoria concentrate)	1.8	4.8	1.3	1.8	22.10	3.90	ND
Magnetic.....	3.2	47.0	5.9	25.0	<.05	<.02	ND
HT-HI magnetic separation (thorium-uranium flotation tails):							
Conductor, HI magnetic (ilmenite concentrate).....	9.2	47.0	9.3	19.0	ND	ND	ND
Conductor, HI nonmagnetic (chromite concentrate).....	2.5	4.3	22.0	2.9	ND	ND	ND
Nonconductor (sand).....	25.3	7.4	1.2	.7	ND	ND	ND

ND Not determined.

[1]Also 0.08 oz/ton gold.

TABLE 12. - Distribution of major constituents in products from Merced River HM concentrates

Product	Distribution, pct					
	Fe_2O_3	Cr_2O_3	TiO_2	ThO_2	U_3O_8	Pt
Head (cleaner concentrate).....	100	100	100	100	100	100
LI magnetic separation:						
Magnetic.....	86	25	28	<1	<1	13
Nonmagnetic.....	14	75	72	99	-	87
Platinum flotation (LI nonmagnetic):						
Concentrate.....	-	-	-	-	-	78
Tails.....	14	75	72	99	99	9
Thorium-uranium flotation (platinum flotation tails):						
Concentrate.....	3	8	21	57	63	-
Tails.....	11	67	51	42	36	-
HI magnetic separation (thorium-uranium flotation concentrate):						
Nonmagnetic (thoria concentrate).....	-	1	1	56	62	-
Magnetic.....	3	7	20	1	1	-
HT-HI magnetic separation (thorium-uranium flotation tails):						
Conductor, HI magnetic (ilmenite concentrate.....	7	33	44	-	-	-
Conductor, HI nonmagnetic (chromite concentrate).....	2	22	2	-	-	-
Nonconductor (sand).....	2	12	5	-	-	-

The platinum flotation tails were then treated by fatty acid flotation to recover a radioactive mineral concentrate. This radioactive mineral concentrate contained 8.20 wt-pct ThO_2 and 1.44 wt-pct U_3O_8. The ThO_2 and U_3O_8 recoveries were 57 and 63 pct, respectively. Further treatment of this radioactive mineral concentrate by HI magnetic separation yielded a product containing 22.1 wt-pct ThO_2 and 3.9 wt-pct U_3O_8 with overall thorium and uranium recoveries of 56 and 62 pct, respectively. An electron microprobe examination showed the major thorium mineral to be thorite ($ThSiO_4$). Monazite, which contains both thorium and uranium, was detected as well as species containing Ca, Fe, and Si with Th and U in varying ratios. The fatty acid flotation tails and the magnetic fraction from the HI magnetic separator were treated by high-tension (HT) separation followed by a HI magnetic separation to recover ilmenite and chromite. The ilmenite product was low grade, containing about 19 wt-pct TiO_2 and 9.3 wt-pct Cr_2O_3. This fraction contained 44 pct of the total TiO_2. The chromite concentrate was also low grade, containing 22 wt-pct Cr_2O_3 and 2.9 wt-pct TiO_2. The chromite concentrate contained only 22 pct of the total Cr_2O_3.

San Joaquin River

The San Joaquin River HM concentrate containing 0.07 oz/ton gold, 0.02 oz/ton platinum, and 0.38 and 0.06 wt-pct ThO_2 and U_3O_8, respectively, was treated by a processing sequence similar to that of treating the Merced River concentrate, except that no attempts were made to recover chromite and ilmenite products. The concentrate was first treated by amalgamation to recover approximately 99 pct of the gold. The results for recovering magnetite, Pt, ThO_2, and U_3O_8 are shown in table 13. The magnetite fraction contained 65 pct of the concentrate in a product containing, in wt-pct: Fe_2O_3, 97; Cr_2O_3, 0.4; and TiO_2, 0.7. The LI nonmagnetic fraction was treated by the same xanthate flotation techniques used with the Merced River sample to recover a concentrate containing 16.0 oz/ton Pt; only traces of other PGM were present. Of the platinum recovered, 80 pct was in the concentrate.

TABLE 13. - Recovery of magnetite, platinum, and radioactive minerals from San Joaquin River concentrate

Product	Wt-pct	Pt, oz/ton	Analysis, wt-pct		Distribution, pct		
			ThO_2	U_3O_8	Pt	ThO_2	U_3O_8
Head[1] (cleaner concentrate).....	100	0.02	0.38	0.06	100	100	100
LI magnetic separation:							
Magnetic.....	65	.001	<.05	<.02	5	-	-
Nonmagnetic.....	35	.06	1.10	.18	95	100	100
Platinum flotation (LI nonmagnetic):							
Concentrate.....	.1	16.00	ND	ND	80	-	-
Tails.....	34.9	.009	1.10	.06	15	-	-
Uranium-thorium flotation (platinum flotation tails):							
Concentrate.....	6	-	4.00	.66	-	63	67
Tails.....	29	-	.48	.07	-	37	33
HI magnetic separation (uranium-thorium flotation concentrate):							
Magnetic.....	4	-	.37	.03	-	4	2
Nonmagnetic.....	2	-	11.25	1.95	-	59	65

ND Not determined.
[1]Also 0.07 oz/ton gold.

The platinum flotation tails were then treated by fatty acid flotation techniques to recover a product containing 4.0 wt-pct ThO_2 and 0.66 wt-pct U_3O_8. The concentrate contained 63 and 67 pct of the ThO_2 and U_3O_8, respectively. The concentrate was upgraded by HI magnetic separation to recover a product containing 11.25 wt-pct ThO_2 and 1.95 wt-pct U_3O_8. The overall recoveries of ThO_2 and U_3O_8 were 59 and 65 pct, respectively.

Big Tujunga and San Gabriel Rivers

The processing sequence for the recovery of gold, magnetite, and ilmenite from Big Tujunga and San Gabriel Rivers sand samples is shown in figure 5.

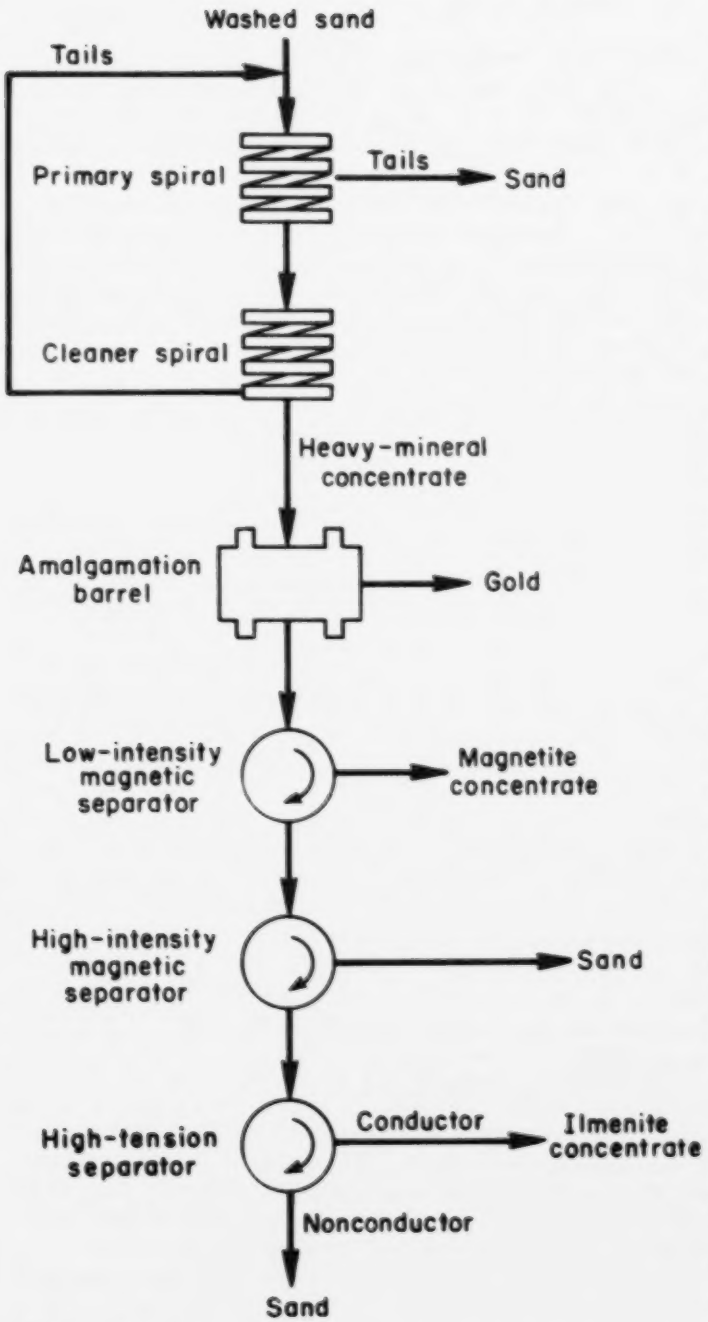

FIGURE 5. - Processing sequence for Big Tujunga, San Gabriel, Otay, and Sweetwater Rivers sand samples.

The analysis of the product and distribution of major constituents are shown in table 14. The respective cleaner concentrates, containing 0.006 and 0.02 oz/ton gold, were treated by amalgamation to essentially recover 100 pct of the gold from both samples. The cleaner concentrates were fractionated by LI magnetic separation to yield magnetite products containing 21 and 31 pct of the respective feed materials. The Big Tujunga and San Gabriel magnetic concentrates contained 90 and 93 wt-pct Fe_2O_3, and 3 and 1 wt-pct TiO_2, respectively.

The ilmenite fraction prepared from the Big Tujunga River sample by HI magnetic separation was upgraded by HT separation to yield a conductor product containing 42 wt-pct TiO_2. Of the TiO_2 recovered, 91 pct was in this fraction. The TiO_2 and Fe_2O_3 contents of the Big Tujunga ilmenite product are similar to the TiO_2 and Fe_2O_3 contents of domestic rock ilmenite concentrates that are commercially utilized.

The ilmenite fraction prepared from the San Gabriel River concentrate by HI magnetic separation contained 18 wt-pct TiO_2 and had 83 pct of the total TiO_2. Treating the HI magnetic fraction further by HT separation did not upgrade the TiO_2 content enough to yield an acceptable product. Ilmenite recovery from the San Gabriel concentrate did not appear practical.

TABLE 14. - Recovery of magnetite and ilmenite from Big Tujunga River and San Gabriel River concentrates

Product	Wt-pct	Analysis, wt-pct		Distribution, pct	
		Fe_2O_3	TiO_2	Fe_2O_3	TiO_2
BIG TUJUNGA RIVER					
Head[1] (cleaner concentrate).....	100	42	21	100	100
LI magnetic separation:					
Magnetic.....	21	90	3	46	3
Nonmagnetic.....	97	29	25	54	97
HI magnetic separation (LI nonmagnetic):					
Magnetic.....	53	41	35	52	92
Nonmagnetic.....	26	4	3	2	5
HT separation (HI magnetic):					
Conductor.....	44	48	42	51	91
Nonconductor.....	9	5	2	1	1
SAN GABRIEL RIVER					
Head[2] (cleaner concentrate).....	100	47	6	100	100
LI magnetic separation:					
Magnetic.....	31	93	1	65	5
Nonmagnetic.....	69	23	8	35	95
HI magnetic separation (LI nonmagnetic):					
Magnetic.....	27	38	18	32	83
Nonmagnetic.....	42	5	2	3	12

[1]Also 0.06 oz/ton gold.
[2]Also 0.02 oz/ton gold.

Otay and Sweetwater Rivers

A processing sequence developed for recovery of gold, magnetite, and ilmenite from Otay and Sweetwater Rivers sand samples is shown in figure 5. The same sequence was used for both samples because the contained minerals were similar. The analysis of the individual products and distribution of major constituents are shown in table 15. The Otay and Sweetwater HM cleaner concentrates contained 0.02 and 0.09 oz/ton gold, respectively. Gold recovery by amalgamation was essentially 100 pct for both samples.

TABLE 15. - Recovery of magnetite and ilmenite from Otay River and Sweetwater River concentrates

Product	Wt-pct	Analysis, wt-pct		Distribution, pct	
		Fe_2O_3	TiO_2	Fe_2O_3	TiO_2
OTAY RIVER					
Head[1] (cleaner concentrate).....	100	35	25	100	100
LI magnetic separation:					
Magnetic.....	8	91	2	21	1
Nonmagnetic.....	92	30	27	79	99
HI magnetic separation (LI nonmagnetic):					
Magnetic.....	61	44	40	77	98
Nonmagnetic.....	31	2	1	2	1
HT separation (HI magnetic):					
Conductor.....	53	50	47	74	98
Nonconductor.....	8	11	<1	3	-
SWEETWATER RIVER					
Head[2] (cleaner concentrate).....	100	49	10	100	100
LI magnetic separation:					
Magnetic.....	34	91	3	64	10
Nonmagnetic.....	66	27	14	36	90
HI separation (LI nonmagnetic):					
Magnetic.....	57	31	16	35	89
Nonmagnetic.....	9			1	1
HT separation (HI magnetic):					
Conductor.....	19	49	42	19	80
Nonconductor.....	38	21	2	16	9

[1]Also 0.02 oz/ton gold.
[2]Also 0.09 oz/ton gold.

About 8 pct of the Otay River concentrate was recovered in a magnetite product containing 91 wt-pct Fe_2O_3 and 2.0 wt-pct TiO_2. Fifty-three percent of the concentrate was recovered in an ilmenite product containing 47 wt-pct TiO_2 and 50 wt-pct Fe_2O_3. The Otay ilmenite product contained 98 pct of the TiO_2 in the cleaner concentrate.

The magnetite product prepared by LI magnetic separation of the Sweetwater River concentrate contained 34 pct of the concentrate. This product contained 91 wt-pct Fe_2O_3 and 3.0 wt-pct TiO_2. The ilmenite product prepared by HI magnetic separation followed by HT separation contained 42 wt-pct TiO_2 and 49 wt-pct Fe_2O_3. Eighty percent of the TiO_2 in the cleaner concentrate was recovered in the ilmenite product. The TiO_2 and Fe_2O_3 contents of the Otay and Sweetwater ilmenite are similar to those of domestic rock ilmenite concentrates.

DISCUSSION AND CONCLUSIONS

The occurrence of heavy minerals in central and southern California sand and gravel deposits is widespread. The major economic byproduct minerals present were magnetite, ilmenite, and gold. In some localities, platinum,

radioactive minerals and chromite occur in significant quantities. Recovery of 90 pct of the heavy minerals in concentrates containing up to 90 wt-pct HM was obtained with a spiral concentrator. Gold was recovered by treating the concentrates with conventional amalgamation techniques. Individual magnetite, ilmenite, and chromite concentrates were obtained by using LI magnetic, HI magnetic, and HT separation techniques. Platinum and radioactive minerals were recovered by flotation techniques.

Additional onsite concentration tests should be performed to accurately evaluate the recovery of byproduct gold, magnetite, and ilmenite from selected sites. A cost evaluation could be made from the mineral recovery data. The continuing increase in value of gold and other byproduct minerals warrants the assembly of additional recovery data.

The most abundant byproduct heavy mineral in central and southern California as well as in northern California (7) is magnetite. The potential use of byproduct alluvial magnetite for the preparation of iron by a Midrex-type process should be considered. The analyses of magnetite concentrates obtained as byproducts from sand and gravel operations in central and southern California are shown in table 16 along with those from northern California obtained in our previous work. The magnetite concentrates had a Fe_2O_3 content of more than 90 wt-pct with minimal quantities of alumina, silica, phosphorus, and sulfur.

TABLE 16. - Analysis of byproduct magnetite concentrates from California

Source	Wt-pct						
	Fe_2O_3	Cr_2O_3	TiO_2	SiO_2	Al_2O_3	P	S
Merced River.....	93	1.1	1.9	1.5	0.4	0.11	<0.01
San Joaquin River	97	.4	.7	1.2	.9	.15	<.01
Kaweah River.....	90	.9	3.7	4.4	.2	.12	.07
Los Gatos Creek..	92	.19	2.4	5.3	.7	.06	<.01
Little Rock Creek	89	.11	2.2	2.2	3.8	.08	<.01
Big Tujunga River	90	.08	3.3	3.9	3.5	.06	<.01
San Gabriel River	93	.07	1.3	3.6	2.0	.08	<.01
Santa Ana River..	86	.10	4.2	3.2	3.2	.12	.02
Sweetwater River.	91	.16	3.0	2.7	.7	.04	<.01
American River[1]..	92	1.0	3.4	2.5	1.2	.02	.02
Yuba River[1].....	88	1.9	4.1	2.6	1.8	.04	.04

[1]Reported in our previous work (7-8).

Successful recovery of byproduct minerals depends on the development of markets for the mineral concentrates and the incorporation of high-capacity concentrating equipment into the sand washing circuit of the plants to prepare HM concentrates. Equipment such as the Reichert cone or Cleveland jig with a low initial and operating cost can be utilized. A plant using relatively high-cost magnetic and HT separation equipment to produce marketable mineral concentrates may be built in a central location to treat the HM concentrates obtained from nearby individual sand and gravel operations.

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